The effect of striped bass predation on recovery of the endangered Sacramento River winter chinook: A Bayesian population viability analysis

Steve Lindley and Michael Mohr
Santa Cruz/Tiburon Laboratory, Southwest Fisheries Science Center
National Marine Fisheries Service

Abstract- *Enhancing the Sacramento River striped bass population poses a potential threat to the endangered winter chinook salmon. In order to assess the risk of a striped bass stocking program, a Bayesian population dynamics model for winter chinook was developed that includes the effect of predation by striped bass. A prior distribution for striped bass predation rate was developed by applying a Bayesian hierarchical model to published stomach contents data. After fitting the population dynamics model to winter chinook spawning escapement data, the model was used to examine the influence of striped bass population size on the probability of winter chinook extinction and recovery. The model suggests a striped bass population stabilization program would increase winter chinook extinction risk only slightly, but increasing the population of adult striped bass from 700,000 to 3 million would more than double extinction risk.*

Background

The Sacramento River system is home to a variety of native and non-native fishes, including the endangered winter chinook salmon (*Oncorhynchus tshawytscha*) and the introduced striped bass (*Morone saxatalis*). Winter chinook were fairly abundant as recently as the late 1960s, but have declined dramatically since then (Fig. 1). Many causes for decline have been identified, including habitat loss, high water temperatures, inadequately screened water diversions, and predation (NMFS, 1997). Winter chinook were listed as an endangered species under the federal Endangered Species Act in 1994. The listing requires state and federal agencies to consult with the National Marine Fisheries Service (NMFS) if their actions might result in take of winter chinook.

Striped bass were introduced to the San Francisco Bay/Delta in the late 1800s. The population grew to support a commercial and recreational fishery in the early part of this century. Since the mid 1960s, both winter chinook and striped bass populations have declined (Fig. 2), in part, due to the operation of the State and Federal water projects. In 1986, the California Department of Water Resources and California Department of Fish and Game (CDFG) agreed on the mitigation requirements for expansion of the State's pumping capacity at the Harvey O. Banks Pumping Plant. Pursuant to this agreement the State is encumbered with an obligation to mitigate the effect of the pumps on fishery resources including striped bass. The CDFG would like to direct this mitigation program to ensure continued sport fishing opportunities by net-pen rearing striped bass salvaged at the State and Federal water pumping facilities. These fish would be released back to the river at age 1 or 2, when they are less vulnerable to water diversions. Because striped bass prey on chinook salmon, CDFG needs an incidental take permit from NMFS to implement any striped bass augmentation program. NMFS must determine that the proposed project does not jeopardize the continued existence of winter chinook before issuing the incidental take permit. This paper describes an analytical approach for determining the impact of striped bass stocking on winter chinook extinction risk and recovery probability.

Methods

Addressing the jeopardy question requires an assessment of how a proposed action will alter the probability that the endangered species will persist. Population viability analysis (PVA) is commonly used to quantify the impact of changes in survival rates on the probability of population persistence (Beissinger and Westphal, 1998). At the heart of a PVA is a population dynamics model. In this case, we used an age-structured process-error stock-recruitment model for predicting winter chinook spawning escapement to assess how changes in striped bass abundance alter extinction and recovery probabilities.

Assessing the impact of striped bass stocking on winter chinook requires answering two questions: (1) how many salmon do striped bass eat; and (2) how do changes in striped bass abundance change the probability of winter chinook extinction or recovery. We used Bayesian statistical methods to address these questions, because they allow us to incorporate disparate data sets into the analysis and express predictions about future population changes in terms of probability distributions that include uncertainty arising from limited data.

Relevant data include published striped bass food habits studies performed in the Sacramento River system, estimates of striped bass abundance, estimates of chinook abundance and survival, and estimates of winter chinook spawning escapement. Food habits data were modeled hierarchically (Gelman et al. 1995) to estimate the number of juvenile salmon that each striped bass consumes per day. Chinook abundance and survival information was used to estimate the number of juvenile chinook that could be vulnerable to striped bass predation. Together, these estimates were used to generate a probability distribution for the per-bass predation rate. This distribution was used as an informative prior distribution in the population dynamics model. Winter chinook population data were used to fit a population dynamics model that includes striped bass predation; striped bass abundance was a covariate.

The winter chinook population dynamics model has a form similar to that used by Botsford and Brittnacher (1998), except that the natural log of the growth rate parameter is the sum of several components. These include an underlying population growth rate in the absence of striped bass predation, a striped bass predation effect that is a linear function of striped bass abundance, a density-dependent term, a process error term representing environmental variation, and an effect of major protective actions that were taken to protect winter chinook starting in 1989. Uninformative prior distributions were used for all parameters except the striped bass predation rate parameter.

The model was fit to the winter chinook escapement data using the Sample-Importance Resampling algorithm, producing a joint posterior probability distribution for the model parameters. The posterior distribution was then used with the population dynamics model to simulate the behavior of the winter chinook population under varying levels of striped bass predation.

Analysis of the striped bass stocking plan

CDFG put forward three plans for consideration: a no-action plan, where the adult striped bass population is expected to decline to around 512,000; a stabilization plan, where the adult striped bass population is kept at 700,000 adults; and a more ambitious augmentation plan, where the adult striped bass population is increased to 3,000,000 adults. The likely impact of these plans was evaluated by using the winter chinook population model with the posterior parameter distributions and the various levels of adult striped bass. For each plan, the probability of reaching the quasi-extinction threshold (defined as less than 50 spawners in three consecutive years) and the recovery threshold (defined as more than 20,000 spawners) was computed over a 100-year time horizon. Results are shown in Figure 3.

If no striped bass stocking were to occur, the model predicts that winter-run chinook have a 20% chance of quasi-extinction within 50 years, and a 46% of recovering to 20,000 adults. While most conservation biologists would view a quasi-extinction probability of 20% as uncomfortably high, it is much lower than the certain extinction predicted by a model assuming constant intrinsic growth rate (Botsford and Brittnacher, 1998). The more optimistic prediction is due mostly to the substantial probability that mean population growth rate has increased since winter chinook were listed under the ESA. The decline of the adult striped bass population to 512,000 from 700,000 contributes only a small effect to increased survival probability.

If a striped bass stocking program were conducted such that the striped bass population was stabilized at 700,000 adults, the probability of quasi-extinction in 50 years would rise from 20% to 21%, and the probability of recovery would decline from 46% to 44%. An adult striped bass population of 3,000,000 would have a 52% chance of causing winter-run chinook quasi-extinction and an associated recovery probability of 19% over the 50 year time horizon. If, on the other hand, striped bass predation could be completely eliminated, the probability of quasi-extinction would decline to 16% and the probability of recovery would rise to 52% at the 50-year time horizon. These analyses indicate that while striped bass predation contributes significantly to extinction risk, winter chinook would still be at risk even in the absence of striped bass.

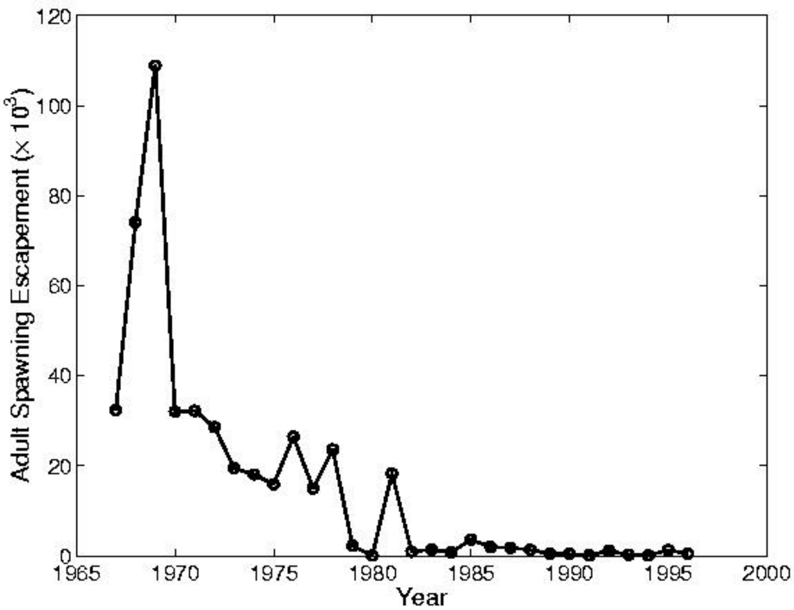

Figure 1. Winter chinook adult spawning escapement (age 3 and 4).

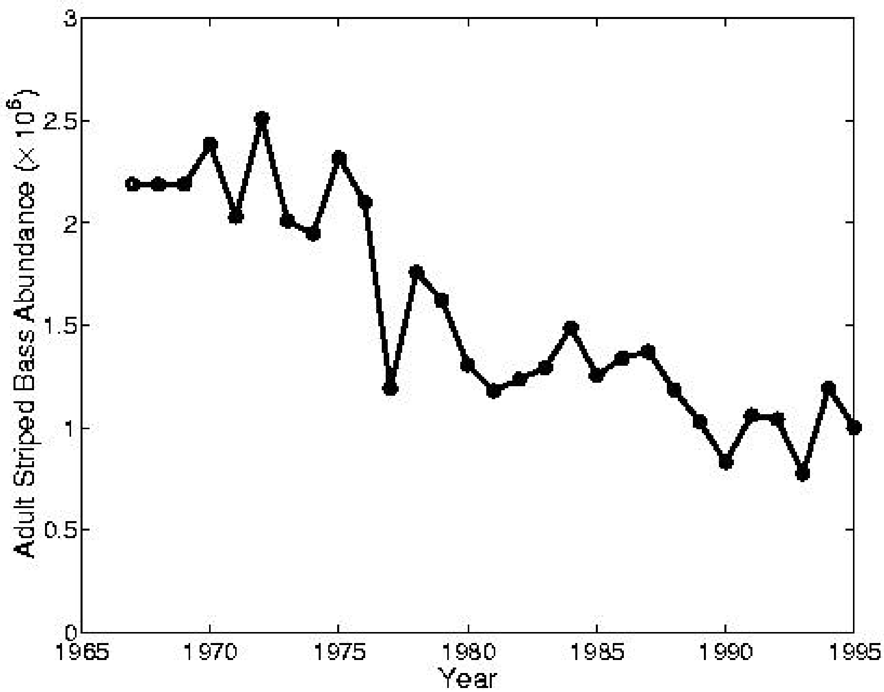

Figure 2. Adult striped bass abundance in the Sacramento-San Joaquin rivers and estuary (age 3+).

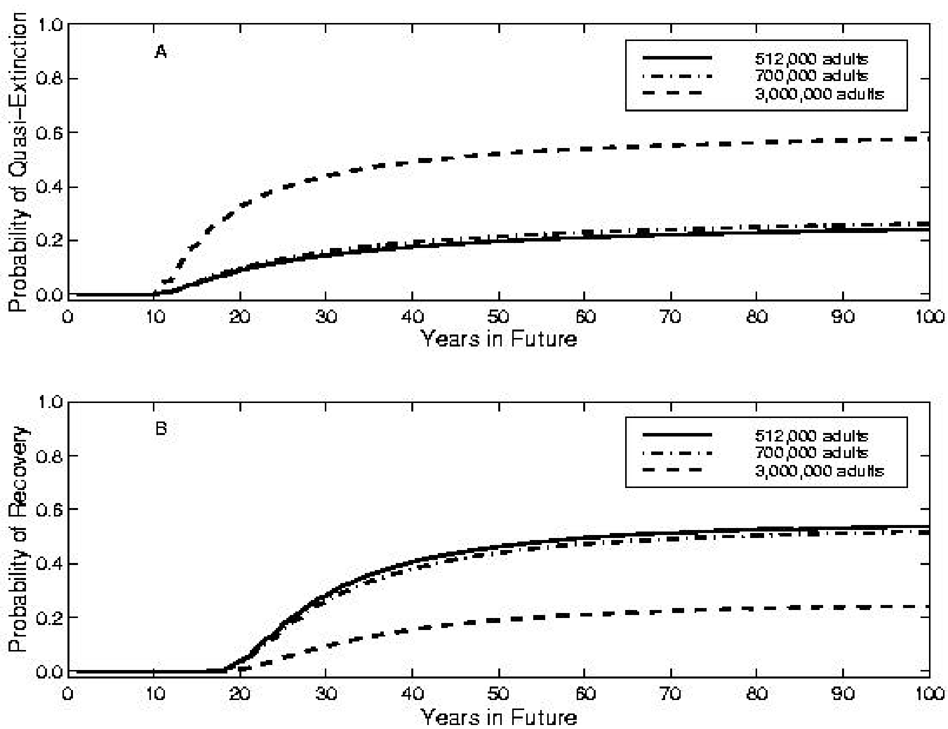

Figure 3. Probilities of winter-run chinook quasi-extinction (A) and recovery (B) under different adult striped bass population sizes.

References

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